Computer Labs: The PC's Real Time Clock (RTC)

2º MIEIC

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The Real Time Clock (RTC)

- Integrated circuit that maintains:
  - The date and
  - The time of the day

  even when the PC is switched-off and unplugged
- In addition, it:
  - Includes alarm functionality and can generate interrupts at specified times of the day;
  - Can generate interrupts periodically
  - Includes at least 50 non-volatile one-byte registers, which are usually used by the BIOS to store PC's configuration
- Modern RTCs are self-contained subsystems, including:
  - A micro lithium battery that ensures over 10 years of operation in the absence of power (when the power is on, the RTC draws its power from the external power supply)
  - A quartz oscillator and support circuitry

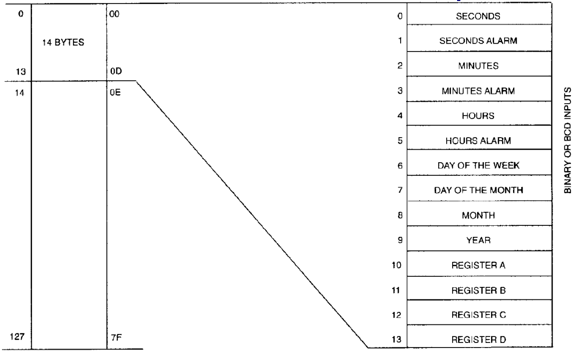
Lab 6: The RTC (2013)

- Write functions:

  ```
  int test_config();
  int test_date();
  int test_int();
  ```

  that require interfacing with the RTC
- These functions are not the kind of functions that you can reuse later in your project
  - The idea is that you design the lower level functions (with the final project in mind).
- What's new?
  - Use the RTC
    - Asynchronous concurrent access to shared registers
  - Develop interrupt handler in assembly (mixed C-assembly programming)
  - Some details of what you'll have to implement revealed only in class

The RTC's Internal Address Space



- ... is an array of at least 64 one-byte registers, whose content is non-volatile. Each register can be:
  - Addressed individually
  - Both read and written
- The first 10 registers are reserved for time-related functionality
- The following 4 registers are reserved for control of the RTC
- The remaining registers can be used for arbitrary purposes

Access to the RTC in the PC

- The PC uses two ports to access the RTC's internal registers:

  RTC_ADDR_REG on port **0x70**, which must be loaded with the address of the RTC register to be accessed

  RTC_DATA_REG on port **0x71**, which is used to transfer the data to/from the RTC's register accessed
- To read/write a register of the RTC requires always:
  1. writing the address of the register to the RTC_ADDR_REG
  2. reading/writing one byte from/to the RTC_DATA_REG

Time of the Day, Alarm and Date Registers

ADDRESS LOCATION	FUNCTION	DECIMAL RANGE	DATA MODE RANGE	
			BINARY	BCD
0	Seconds	0–59	00–3B	00–59
1	Seconds Alarm	0–59	00–3B	00–59
2	Minutes	0–59	00–3B	00–59
3	Minutes Alarm	0–59	00–3B	00–59
4	Hours, 12-hour Mode	1–12	01–0C AM, 81–8C PM	01–12AM, 81–92PM
	Hours, 24-hour Mode	0–23	00–17	00–23
5	Hours Alarm, 12-hour	1–12	01–0C AM, 81–8C PM	01–12AM, 81–92PM
	Hours Alarm, 24-hourr	0–23	00–17	00–23
6	Day of the Week Sunday = 1	1–7	01–07	01–07
7	Date of the Month	1–31	01–1F	01–31
8	Month	1–12	01–0C	01–12
9	Year	0–99	00–63	00–99

- It is possible to program whether the data format is binary or BCD, but this applies to all registers
- It is also possible to program whether the hours range from 0 to 23 or 1 to 12 (plus AM and PM), but this applies both to the time and the alarm registers

Reading the Date or the Time of the Day (1/2)

Issue The registers with the date and the time of the day are updated **asynchronously** by the RTC every second

- These registers are just an image of non-accessible counters that are updated automatically as determined by the signal generated by the (internal) quartz oscilator

Problem What if there is an update while we are reading the time/date?

- E.g. the time updates from 7:32:59 to 7:33:00.

Question How big can the error be?

- Does it matter the order in which registers are read?

Reading the Date or the Time of the Day (2/2)

Solution The RTC offers 3 mechanisms to overcome this issue:

Update in progress flag (UIP) of the RTC

- The RTC sets the `UIP` of `REGISTER_A` 244 μs before starting the update and resets it once the update is done

Update-ended interrupt of the RTC

- If enabled, the RTC will interrupt at the end of the **update cycle**, the next cycle will occur at least 999 ms later
- `Register_C` should be read in the IH, to clear the IRQF

Periodic interrupt of the RTC

- Periodic interrupts are generated in such a way that updates occur sensibly in the middle of the period (actually, 244μs after)
  - As long as the period is long enough
  - Thus, after a periodic interrupt occurs, there are at least $P/2 + 244\mu$ seconds before the next update

Contents

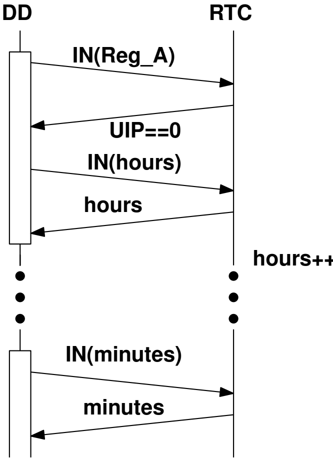
Preemptions and Races Reading the Time

What if: the DD is **preempted** while reading the time, e.g.?

Note The arrows labeled `IN(XXX)` represent one output to port `0x70` and one input from port `0x71`

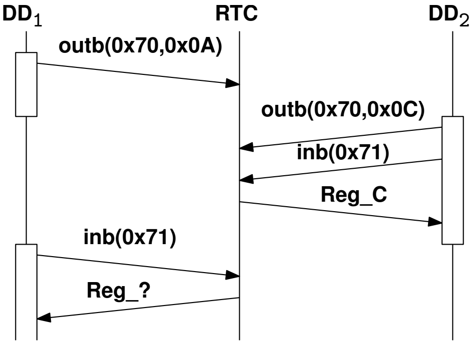
How to prevent this?

- Disable interrupts before starting to read (what?)
- Enable interrupts again, after reading
- Define assembly functions to enable/disable interrupts



Other Races caused by Preemptions

What if: the DD is **preempted** while trying to access the RTC and the preempting process accesses the RTC?



How to prevent this?

- Disabling interrupts **may not work** with more than one processor
  - Interrupts are disabled only on one processor/core
- **Need not worry** with this for the RTC in Minix
- You'll study **concurrency** problems in the OS class

Updating the Date or the Time of the Day

Problem Asynchronous updates can also make time/date updates inconsistent

Solution Set the `SET` bit of `Register_B` before updating

- It prevents the RTC from updating the time/date registers with the values of the date/time keeping counters
- At the end of the update the `SET` bit should be reset so that the RTC updates the counters with the values of the registers

Question Can we use the `SET` bit of `REGISTER_B` also for reading the date/time registers?

Alarm Registers

- The alarm registers allow to configure an alarm
- When the time of day registers match the corresponding alarm registers, the RTC alarm generates an alarm interrupt, if that interrupt is enabled at the RTC
  - Bit `AIE` (5) of `REGISTER_B`
- The RTC supports **don't care** values – values with the 2 MSB set (`11XXXXXX`)– for alarm registers
  - These values match any value of the corresponding register of the time of day register set
  - This makes it possible to configure alarms for multiple times of the day, without changing the contents of the alarm registers
    - For example, if all 3 alarm registers are set to "don't care", then the RTC will generate an alarm every second

Interrupts

- The RTC can generate interrupts on 3 different events
  - Alarm interrupts (AI)
  - Update interrupts (UI)
  - Periodic interrupts (PI) with a period between 122 μs and 0.5 s, as determined by bits `RS0-RS3` in `REGISTER_A`
- Each of the interrupts can be enabled/disabled individually, using bits `AIE`, `UIE` and `PIE` of `REGISTER_B`
- The RTC has only one IRQ line, which is connected to line IRQ0 of PIC2, i.e. IRQ8.
  - The source of the interrupt can be determined by checking the flags `AF`, `UF` and `PF` of `REGISTER_C`
  - Note that more than one of these flags may be set simultaneously
  - `REGISTER_C` must be read to clear these flags, even if there is only one enabled interrupt
- Flags `AF`, `UF` and `PF` of `REGISTER_C` are activated upon the corresponding events even if interrupts are disabled
  - It is possible to use polling to check for the corresponding events

Control/Status Register A

REGISTER_A

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
UIP	DV2	DV1	DV0	RS3	RS2	RS1	RS0

UIP If set to 1, update in progress. Do not access time/date registers

- More precisely, this bit is set to 1, 244μs before an update and reset immediately afterwards

DV2-DV0 Control the couting chain (not relevant)

RS3-RS0 Rate selector – for periodic interrupts and square wave output

Control/Status Register B

REGISTER_B

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
SET	PIE	AIE	UIE	SQWE	DM	24/12	DSE

SET Set to 1 to inhibit updates of time/date registers.

PIE, AIE, UIE Set to 1 to enable the corresponding interrupt source

SQWE Set to 1 to enable square-wave generation

DM Set to 1 to set time, alarm and date registers in binary. Set to 0, for BCD.

24/12 Set to 1 to set hours range from 0 to 23, and to 0 to range from 1 to 12

DSE Set to 1 to enable Daylight Savings Time, and to 0 to disable

- Useless: supports only old US DST ...

IMPORTANT Do not change **DM**, **24/12** or **DSE**, because it may interfere with the OS

- In any case, changes to **DM** or **24/12** require setting the registers affected by those changes

Control/Status Registers C and D

REGISTER_C

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
IRQF	PF	AF	UF	0	0	0	0

IRQF IRQ line active

PF Periodic interrupt pending

AF Alarm interrupt pending

UE Update interrupt pending

REGISTER_D

BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
VRT	0	0	0	0	0	0	0

VRT Valid RAM/time – set to 0 when the internal lithium battery runs out of energy – RTC readings are questionable

Lab 6 (2013): `test_config()`

What? Read and display the configuration of the RTC

- The time of day is the state, not the configuration
- The value of the alarm registers ... should be considered as state, not as configuration

For class preparation need not display the configuration in a fancy way

- Just show the value of the registers in hexadecimal

Lab 6 (2013): `test_date()`

What? Display the date and time, in a human readable way

- Need not support all formats, only those the RTC is configured with
- The mechanism to be used to ensure consistency will be told in class
  - Your implementation can use another mechanism, but you will be penalized (between 50 and 67%)

For class preparation need not display the configuration in a fancy way

- Just show the value of the registers in hexadecimal

Example Code: Waiting for Valid Time/Date

```
void wait_valid_rtc(void) {
    unsigned long regA = 0;

    do {
        disable();
        sys_outb(RTC_ADDR_REG, RTC_REG_A);
        sys_inb(RTC_DATA_REG, &regA);
        enable();
    } while ( regA & RTC_UIP);
}
```

- Assuming that functions `enable()`/`disable()` enable/disable processor interrupts
- May not be what you want!!!
  - What if code is preempted or interrupted?

Lab 6 (2013): `test_int()`

What? Handle one of the 3 types of interrupts

- Which one will be told in class
  - Your implementation can handle a different one, but you will be penalized (between 50 and 67%)

How? Need to implement the handler partially in assembly

- At least the I/O part, and may be something else
- The variables to be used in the communication between the assembly code and C code must be declared in assembly
- If you prefer the Intel's syntax, check if it is supported

Example Code: RTC IH in C

```
void rtc_ih(void) {

    int cause;
    unsigned long regA;

    sys_outb(RTC_ADDR_REG, RTC_REG_C);
    cause = sys_inb(RTC_DATA_REG, &regA);

    if( cause & RTC_UF )
        handle_update_int();

    if( cause & RTC_AF )
        handle_alarm_int();

    if( cause & RTC_PF )
        handle_periodic_int();

}
```

Lab6 (2013): Hints for a successful `test_int()`

Read Register C to clear any pending interrupt

- For example, the interrupt may have occurred the last time you run `lab6`, but it was not processed because `lab6` was already out of the interrupt dispatching loop.

Write it in C first and only afterwards in assembly

Assembly file must have **`.S` (upper case 's')** extension

- Otherwise, `gcc` does not call the C pre-processor

Header files used in assembly should include only **#defines**

- In particular, the assembler is not aware of C function prototypes and will generate an error

`sys_iopenable()` must be called, otherwise if you try to execute protected instructions you'll get a somewhat weird message, such as:

```
lab6      255949 0x2ec6 0x22d1 0x28b3 0x100a
```

Further Reading

- Data sheet of a relatively recent RTC IC
- Lab 6 Handout